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Examining Precision Munitions Alternatives: The Average isn't Good Enough (U)

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ABSTRACT

As the military employs more precision munitions to maximize effects and minimize collateral damage, the commander should understand each munition's strengths and weakness. These munitions are usually expensive and in short supply in relation to their less intelligent compatriots. Due to these constraints, engagement planning is limited to specific situations such as urban terrain and targets moving at time of engagement. To compare different types of guidance for precision munition performance in these scenarios, combat modeling usually employs averages for the engagement. The average location of the round in the "basket", average range from target when the seeker "wakes up", and seeker field of view are usually combined into another average such as probability of hit. While these averages provide useful insights, critical limitations are obscured. This paper will use analysis done for the Precision Guided Mortar Munition to examine these types of modeling limitations.

Modeling Precision Munitions

Increasingly, the US military conducts operations in areas and under rules of engagement, which require requiring minimal damage such as urban terrain. To meet these constraints, it has turned to precision munitions to increase lethality and minimize collateral damage. As the type and quantity of precision munitions increases, comparisons between these munitions and future munitions will be conducted in analysis of alternatives required by CJCSI 3170.01C and DOD 5000 series regulations. Many of these analyses are conducted using combat models such as, Combined Arms and Support Task Force Evaluation Model (CASTFORM) and Janus. While these models have the resolution to model individual entities such as combat vehicles and precision guided munitions, the algorithms and data are aggregated to simplify the complexity of the engagement. This simplification leads to an overestimation of precision munitions' capabilities and possible unfavorable outcomes on future battlefields.

Engagement at Karbala

During Operation Iraqi Freedom, a Rick Atkinson, Washington Post reporter, recorded this engagement by the Second Brigade of the 101st Airborne Division.[1] At 1140, a company team was engaged by small arms from a building in Karbala, Iraq. The troops were in a minefield and took three casualties. After the company called for fire support, the Brigade commander decided at 1225 to use close air support to destroy the target, instead of his direct support 105mm howitzers.

At 1235, two F/A 18s armed with Maverick missiles were in the area and an OH-58 Kiowa Warrior helicopter was to lase the west side of the building to minimize effects on friendly troops. The first Maverick went "stupid" because dust interrupted the 34 second track. The F/A 18s and Kiowa Warrior had to break off the engagement. Several minutes later, the Kiowa Warrior was back on station, but the F/A 18s were out of position. After a 5 minute dance, the F/A 18s and Kiowa Warrior were in position to engage again. After launching another Maverick, the missile lost lock and exploded behind the Brigade TOC.

At this point, the Brigade commander decided to use his artillery. At 1325, one hundred 105mm high explosive rounds destroyed the target. This engagement lasted about two hours, two Mavericks caused collateral damage, and high explosive artillery finally destroyed the target. Using our current combat models, this would have been a successful engagement by precision munitions.

Current Combat Models

Most Army analysis of alternative for munitions uses either CASTFORM and/or Janus to evaluate the combat effectiveness of the proposed mix of munitions. Using available documentation, the models' capabilities are shown in Figure 1 below. Since the documentation's publication, both models have been improved and the data enhanced. The bottom line is that engagements such as Karbala are a series of independent events. Each event has associated errors. These errors are usually aggregated to improve run time or minimize cost in developing data. In the real world, a failure in execution by any of these events will cause an unsuccessful engagement. The aggregation of events and data does not capture the independent nature of these events as represented in these combat models or the supporting data.

Janus (July 2000)

- Does observer/system have Line of Sight?
- Does observer have laser designator?
- Does firing unit have precision munition?
- Check target round lase angle?
- Check min range/terrain?

Consider range error, angle of fall, deflection, scan rate.

Castform (March 99)

FO Generated

- FO provides center of footprint, time of mission, LOS. During flight, target assumed to be "tracked"
- Check target-round lase angle
- Satisfy sensor conditions – obscuration, vegetation, reflected energy, tgt not dead
- Check designator acquired
- Check if retain lock (designator alive and conditions above) according to scan time

Fire and forget

- Rank targets/False targets from closest to farthest. Check for munition detect/commit. Apply Pk/Ph.

Considered range error, deflection, aimpoint, scan rate.

5

Figure 1. Example of current combat model capability.[2]

Engagements in Urban Terrain

For this paper, the Army's Precision Guided Mortar Munition (PGMM) will be used as an example to demonstrate the difficulties in modeling precision munitions. The PGMM is fired from the 120mm mortar found in infantry brigades of all types. The proposed range of PGMM is from 12km to 15km. The round will arrive in a "basket" one to two kilometers from the target and the seeker "wake up" and try to lock on the laser designator. The basket is 360m in diameter. This flight profile is shown in Figure 2.

In 1999, Dr. Ellefsen from the San Jose State University conducted a worldwide study of the world's urban areas. In this study, he categorized urban areas into seven terrain zones.[4] These types are found in Figure 3. The US Army Infantry Center utilized these terrain zones in their Analysis of Requirements for a PGMM.[5] A key performance parameter (KPP) in this document specified that the round must be able to engage buildings and vehicles in five of the urban terrain zones with an objective requirement to engage the same targets in the other two zones. In his categories, Dr. Ellefsen's study identified building height and street width.[6] Using this data, the minimum Line of Sight (LOS) angle can be calculated. At this angle, the round will just graze the building on the near side of the street and still hit the base of the building on the other side of the street. A vehicle in the street will have a greater angle.

The greatest acceptable angle of attack on the building is about 45 degrees. This angle will prevent the round from bouncing off the structure and fail to detonating. Angles significantly less than 45 degrees are required for PGMM's proposed shape charge to have the greatest effect on the enemy inside the building or vehicles. Assuming the round will attack at 45 degrees, the mortar round will not be able to engage targets in the Widely Spaced High-Rise Office Building terrain zone. This was a threshold requirement for a KPP in the Analysis of Requirements. If

this requirement had proceeded to the Operational Requirements Document (ORD), the round would have failed its operational test for failing to meet a KPP. Depending on the warhead selected the round could fail to engage in several other urban terrain zones.

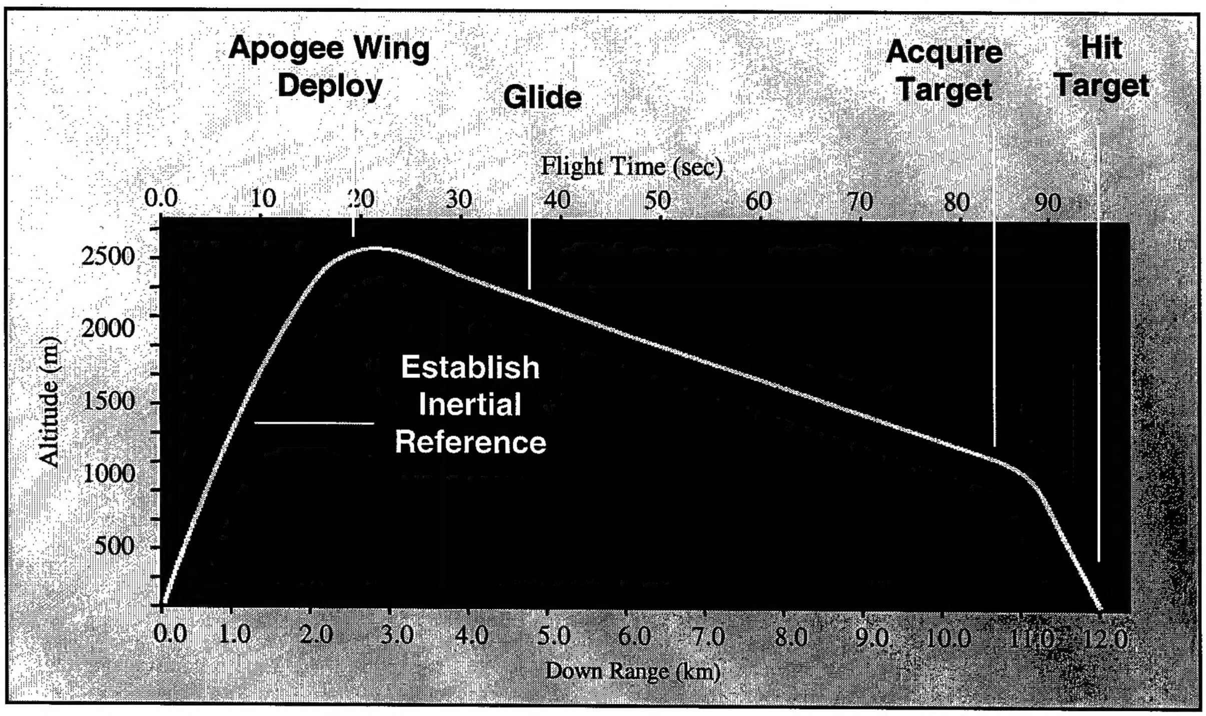

Figure 2. PGMM Flight Profile[3]

Urban Terrain Zone (UTZ)	LOS Angle (Θ)	Percent Worldwide Occurrence
(T) Detached Houses	22°	32%
(T) Widely Spaced Apartment Buildings	22°	29%
(T) Widely Spaced Industrial / Storage Buildings	8°	15%
(T) Attached Houses	17°	10%
(O) Closely - Spaced Industrial / Storage Buildings	20°	10%
(O) Attached & Closely Spaced Inner City Buildings	81°	3%
(T) Widely Spaced High-Rise Office Buildings	57°	1%

T = Threshold, O = Objective

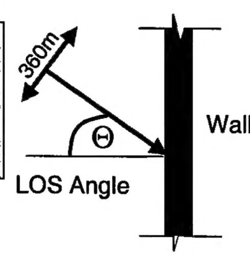

Figure 3. Ability to Hit Targets in Buildings

Now consider PGMM's inherent variation. Its basket is 360m in diameter and the seeker will try to locate the laser between 1000m and 2000m from the target. The average for these parameters is the center of the basket and 1500m from the target. Figure 4 shows a parametric analysis of these parameters. Besides the already identified difficulty of hitting the Widely Spaced High-Rises, these parameters appear to have no effect on the round's ability to engage targets.

When engaging vehicles, the outcome is different. For this analysis, the vehicle is placed in the center of the street. Here the vehicle has maximum standoff from threats on either side of the street. Also, it can move around obstacles to either side. From an analysis standpoint, this represents the next most logical point to place the vehicle. Next to the building on the far side of the street represents little change from the building analysis. Next to the building on the near side of the street would require almost a vertical trajectory which would be impossible as represented in Figure 3.

At the average (center of basket and 1500m range), the round has difficulty engaging a vehicle in the center of the street in the Widely Spaced Apartments and Detached Houses terrain zones. Both are KPP threshold requirements. If the basket calculation point increases to 2000m, vehicles in the Closely Spaced Industrial terrain zones cannot be engaged also. All of these targets can be engaged if the seeker attempts to lock on the laser at its 1000m minimum range from the target

Since the round had problems meeting its KPPs at the average, moving the round to the bottom of the basket was considered. Given this parameter, the Closely Spaced Industrial terrain zone cannot be engaged at 1500m and Attached Houses cannot be engaged at 2000m. Given this analysis, the round must move closer to the target before looking for the laser. Given that CASTFORM does not do Military Operations in Urban Terrain (MOUT) and Janus' capability is limited, this inability to identify these shortcomings would not be represented by average data in these models.

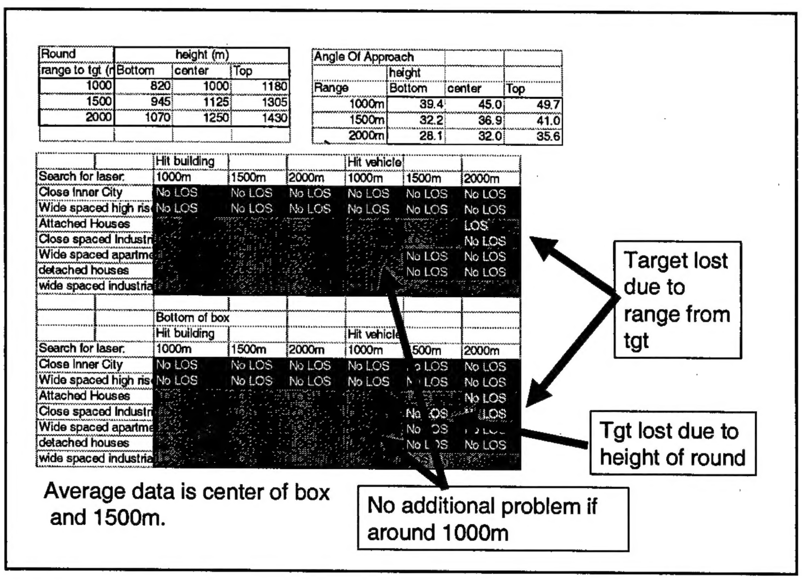

Figure 4. Line of Sight Math

Since the previous analysis shows that the round'must move closer to the target to see the laser, the Army's Program Manager for Mortars calculated shaped routes to place the basket closer to the target. Shortening the range to 8km and the wake up point to 500m the round can engage buildings and vehicles in the Widely Space High-Rise Office Buildings. GPS guidance was also considered, but was not accurate enough for these types of engagements.

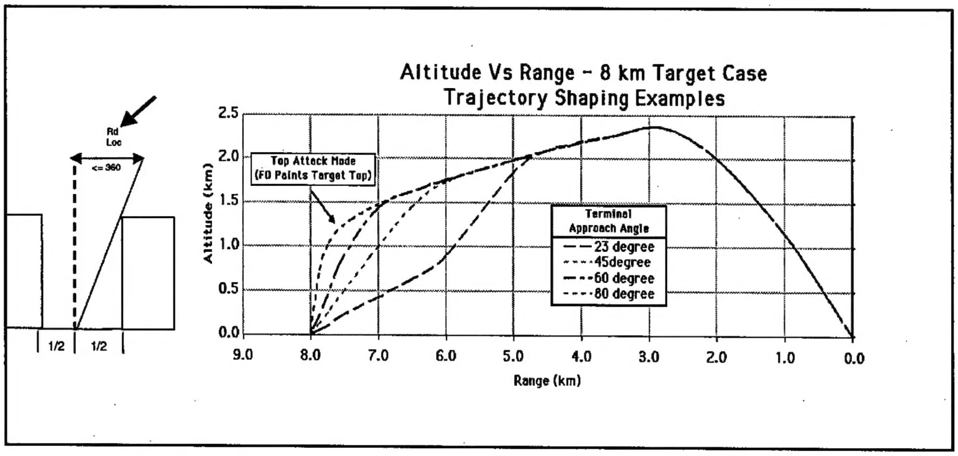

Figure 5. Shaping To Hit Stationary Vehicles.[7]

There are several drawbacks to this engagement. The laser must designate on the top of the vehicle.[8] This means that the forward observer must be significantly higher than the target. If a helicopter is used to designate, air space must be deconflicted and field of view of the seeker must be considered. Analysis of the Field of View will be discussed later. Once again, these considerations are not included in our combat models.

Attacking moving vehicles

Since one of the major benefits of precision munitions is the ability to hit time sensitive targets, the PGMM's Analysis of Requirements desired the ability to engage vehicles moving at 15kph. To analyze this capability, a vehicle moving from the forward observer's left to right was considered. There was no wind to delay, assist, or deflect the round. The target was engaged at 12km with a 360m diameter basket. Field of view for the seeker was 15 degrees. The mortar firing the mission will perform to Army Readiness Training and Evaluation Program (ARTEP) standards. A call for fire will be processed in 75 seconds for a direct lay and 120 seconds for a hasty lay from a gun on the move.[9] The method of engagement will be "at my command" meaning that the observer will tell the gunner when to drop the round into the tube. Since this 40lb round must be held above the gunner's shoulders, the engagement must be completed quickly or additional time must be added as the gunner cannot sustain holding the round above his shoulders.

Given these constraints, Figure 6 outlines the engagement. After the observer calls for fire (CFF), the vehicle moves 313m as the mortar fire direction center and crew prepare the fire mission and round for firing. The forward observer has a window to fire. If he fires too soon, the vehicle will not be in the seeker's field of view (FOV) when it arrives in the basket. If he fires too late, the vehicle will have moved out of the FOV. If the round wakes up at 1000m, the field of view is 120m. If the observer fires the round when the vehicle is 453m to the left of the FOV's center, the vehicle will just enter the FOV when the round arrives. If the observer fires the round when the vehicle is 213m to the left of the FOV's center, the seeker will see the vehicle as it exits the FOV. Converting this to time, the observer has approximately one minute to drop the round. This is acceptable for the average. Now consider, if the round arrives 180m to the left of the basket size. This reduces the observer's reaction time by 43 seconds. The observer has 15 seconds to make the engagement. Given the previous assumptions about

weather, dust, etc., the answer to the ability to engage moving is a definite “maybe”. In our combat models, these engagements are very successful using average data.

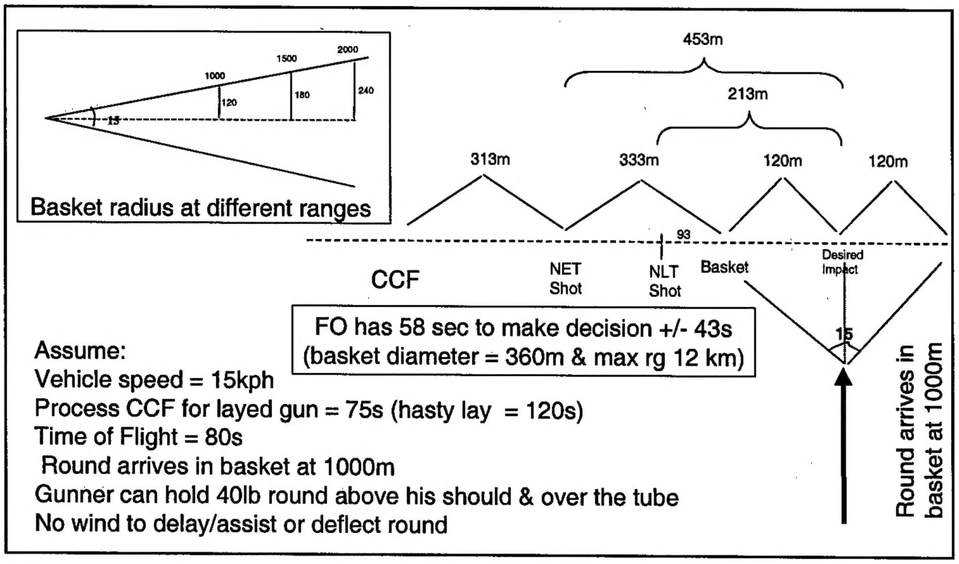

Figure 6. Hitting a Moving Vehicle

Field of View Analysis

Since Field of View (FOV) played an important part in PGMM’s ability to hit the previous target sets and is considered in most combat models, the use of the average data should be reviewed. In examining FOV, a 12km PGMM engagement was conducted with a 15 degree FOV seeker and 360m basket. Figure 7. diagrams this analysis. At the average wake up range of 1500m, the seeker will just be able to see the target if it shows up at the far edge of the basket. Backing up the wake-up range to 2000m, the seeker has no problem arriving anywhere in the basket. Recalling the previous analysis that desired the round to arrive closer, not farther, from the target, the seeker was placed at 1000m. At this range, if the round arrives at the far edge of the basket, the seeker will have an increasingly difficult task in locking on to the laser.

The answer appears to be an increase the seeker’s FOV. Based on PM Mortars' calculations, a 25 degree FOV seeker would see the laser.[10] The difficulty in larger FOV seekers is the same amount of laser light is spread over a larger surface. This decreases the probability that the seeker will have enough light to acquire the laser. This technology’s risk is higher than the existing 15 degree FOV seeker.

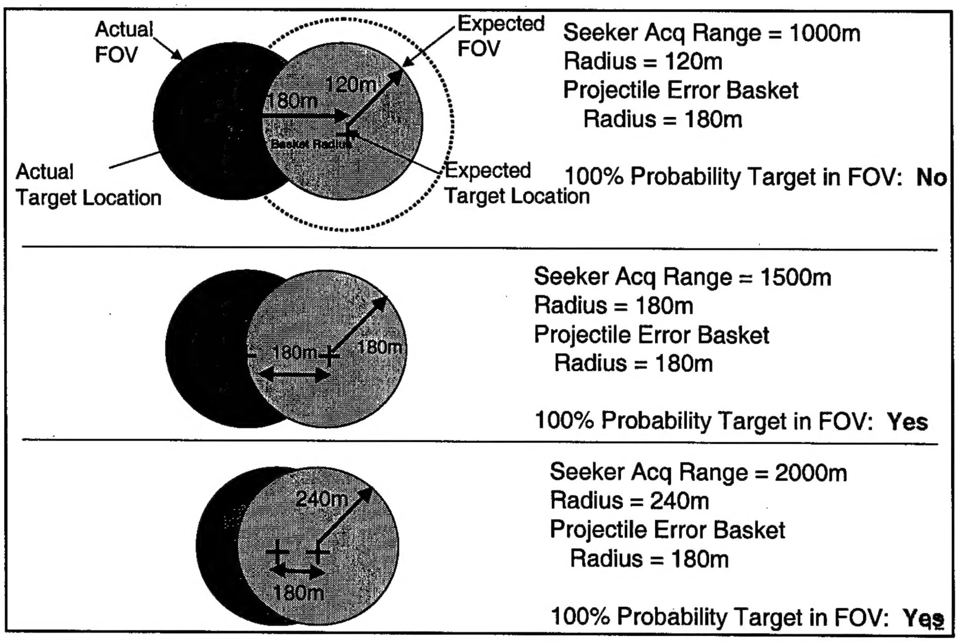

Figure 7. Range- FOV Trade-off

Other Factors

System delivery error and projectile pointing error are other factors included currently in average data supplied to combat models. System delivery error is the ability of the round to arrive at a given point in space. This error includes drift, gun misalignment, and crosswind. Projectile pointing error is the ability of the round to look in the correct direction when it arrives in the basket. The round could point the seeker up, down, left, or right depending on the weather conditions, round balance, or other factors. These factors and others have been combined into the basket error used in the previous analysis.

Figure 8 shows PM Mortars' calculation for PGMM at various ranges. The interesting observation from comparing these tables is that system delivery error goes down as range increases, but projectile pointing error goes up as range increases. These factors are different enough that they do not offset each other. From previous analysis, if either occurs, the engagement will be a failure. Is an average acceptable for a 0 or 1 engagement?

System Delivery Error (SDE): System Delivery Error includes:

- an IMU with 50 deg/hr drift, 500 ppm scale factor,
- 5 mr gun misalignment
- 2 km/hr crosswind error

Range from Gun (m)	Delivery Error (radius in m 1.0km acq.)	Delivery Error (radius in m 1.5km acq.)	Delivery Error (radius in m 2.0km acq.)	Delivery Error (radius in m 2.5km acq.)
8 km	86.4	77.9	69.7	61.8
9 km	104.4	95.2	86.4	77.9
10 km	123.7	113.9	104.4	95.2
11 km	144.2	133.8	123.7	113.9
12 km	166	155	144.2	133.8

Projectile Pointing Error (PPE):

Average Values

	Acquire Range				
	1000	1500	2000	2500	3000
8km	7.1	9.5	11.2	12.2	12.7
9km	7.9	10.6	12.7	14.1	14.9
10km	8.6	11.7	14.2	16.0	17.2
11km	9.3	12.8	15.6	17.8	19.3
12km	9.9	13.8	17.0	19.5	21.4

Figure 8. Error Variation[11]

<u>What about this?</u>

Another factor not included in combat models is the physics of the round actually making the engagement. The round must have enough energy and control surfaces to accomplish the turn to the objective. In PM Mortars' calculation for PGMM in Figure 9, a round could actually turn completely around and engage the gun that fired the round. As range increases, the round's ability to move off the gun target line decreases. At 10km, the round has lost all of its maneuvering energy and functions like a standard mortar round. To engage targets discussed previously, the ranges must be much less than the 12km used in this analysis. When this factor is considered, the round has a maneuvering range of about 7.5km or about the range of an existing dumb round today. 7.5km gives the round the ability to maneuver off axis 90 degrees left or right. The reason for increasing a PGMM's range is to gain maneuvering energy for closer engagements.

Today's combat models do not even consider this kind of physics in their engagements. It could be combined in the aggregate data, but it is another factor in the chain of failure that could overestimate the effectiveness of the munition.

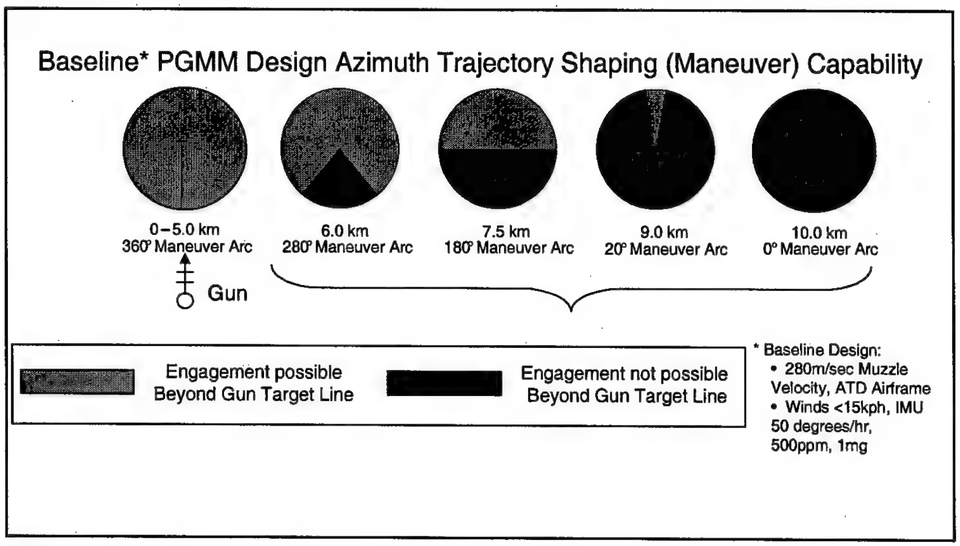

Figure 9. Ability to Maneuver Off the Gun-Target Line[12]

<u>So What!</u>

The Army's Material System Analysis Agency did some analysis of PGMM's ability to engage a target in urban terrain from various directions. These templates were based on Dr. Ellefsen's study. In Figure 10, the streets are narrow and the buildings are 2-3 story, so the round can arrive from many directions as indicated by a GO ray. The closeness of the vehicle to the three story building on the direction of flight and the narrow street to the bottom of the figure create NG conditions. In Figure 11, the streets are wider, the three story buildings are to the left, and the vehicle's location close to the two story building on the right create the NG conditions. Attack is limited to three directions. Figure 12 has the wide streets with higher buildings. This condition leaves only attacks from the bottom of the figure. The buildings toward the bottom of these templates are key terrain. Enemy troops familiar with the area should try to occupy these buildings. Friendly observers must not only try to move into these buildings to place the laser spot on the top of the vehicle, but must have knowledge of several blocks in any direction. They must prevent the round from hitting buildings on its approach. The fire direction center will have to make similar calculations to keep the round from hitting friendly aircraft and terrain features on the inbound route. Placing a precision round at a given point in space, looking a specific direction/angle, and keeping the laser on target for the specified length of time in all weather conditions will be difficult. Our combat models do not represent this type of situation.

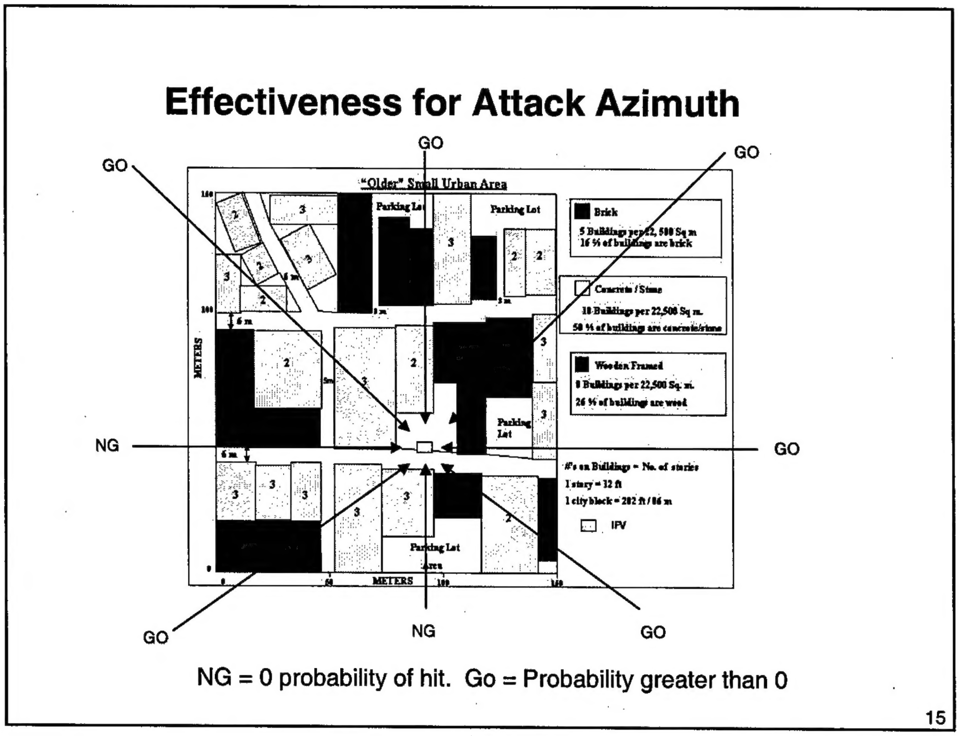

Figure 10. Narrow Streets – 2-3 Story Buildings[13]

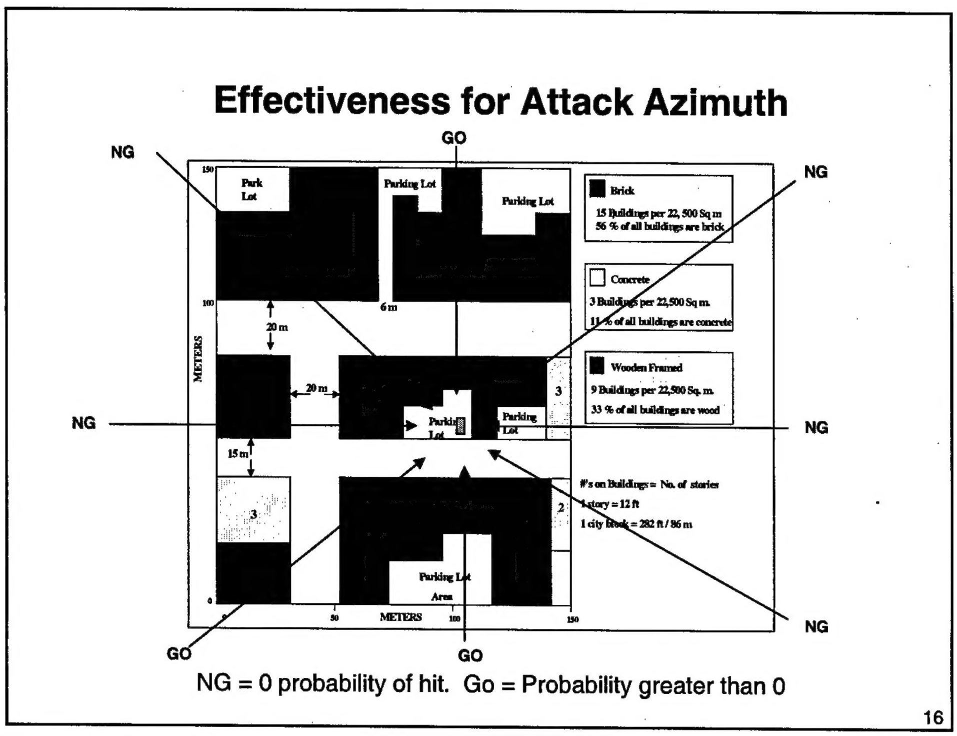

Figure 11. Wider Streets – 2-3 Story Buildings[14]

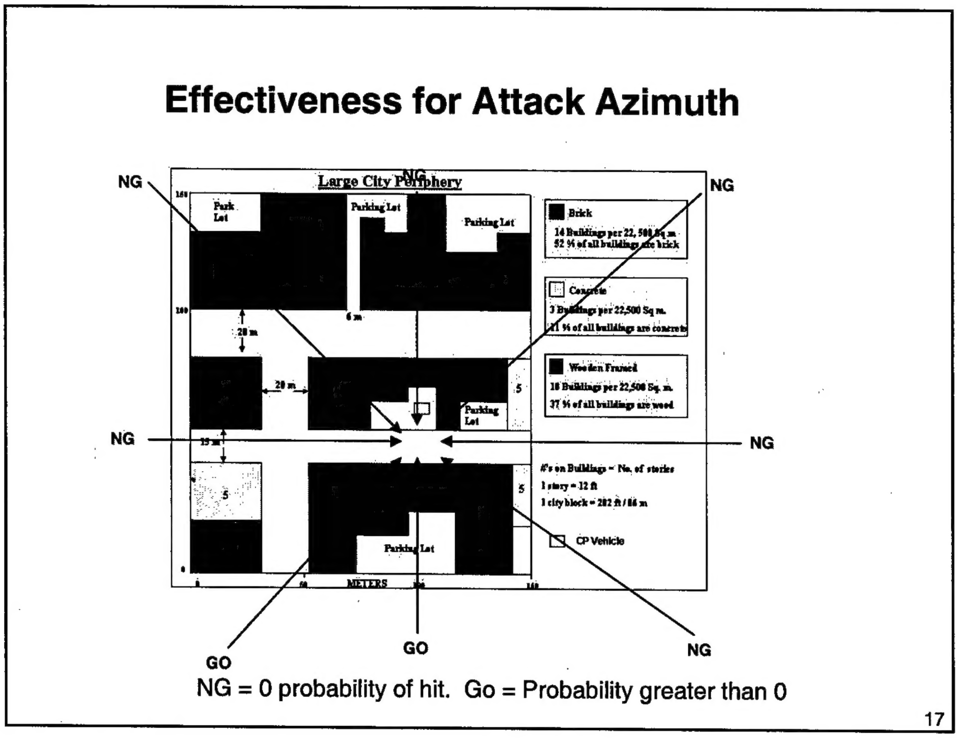

Figure 12. Wide Streets – Tall Buildings[15]

<u>Conclusions</u>

Aggregation in our combat models over-represents the capability represented by precision munitions. Successful engagements in our combat models would not be successful in the real world. The algorithms need to include more factors. Resolution needs to be increased and computer speed increased to allow more entities. Better data needs to be collected. The test community can acquire better data, but the modeling community will need to contribute funds to have a seat at the table. As the US military increases its inventory of precision munitions, the modeling community must be able to represent and compare the differences between the munitions. This will result in better requirements and save money by creating achievable standards based on solid analysis.

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